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THE LIBYAN OASIS OF KHARGA

BY

ELLSWORTH HUNTINGTON.

A hundred miles west of the Nile valley, in the latitude of Luxor, the barren plateau of Libya is broken by a string of depressions containing oases. Formerly they could be reached only by a slow camel-journey of four or five days across a scorching and well-nigh waterless stretch of verdureless upland, sometimes among sand dunes, but chiefly over broad expanses of rough limestone from 1,000 to 1,800 feet above the sea. To-day a railroad has been built and the journey can be made in a few hours. Among the oases perhaps the most interesting is that of Kharga, lying 400 miles south of the Mediterranean Sea. In approaching it over the dry plateau one suddenly finds himself at the top of a line of cliffs, from 600 to 1,000 feet high, running north and south. At their foot lies the oasis, a poor, desolate place, which yet seems fruitful because it is not utter desert.

Kharga is a depression about 115 miles long, from north to south and from 12 to 50 miles wide east and west. It is narrowest at the south, but toward the north it expands and sends off a branch to Dakhla, another oasis, lying 90 miles to the west. On the east and north sides of the Kharga depression, steep cliffs form a comparatively straight border; on the west and south, however, there is no definite border, and the land rises gently to the surrounding desert. The reason for the existence of cliffs to the north and east, but not to the south and west, is that the cretaceous and tertiary strata of which the country is composed dip toward the east and north. During the long process of erosion the softness of certain strata has allowed them to be worn back along the plane of the dip, leaving the underlying hard strata to form the floor of the depression, in most places, and causing the formation of cliffs where hard overlying strata have been undermined. No one knows exactly what has become of the material which has been removed in making the depression. Perhaps it has been blown away by the wind; or possibly at some former period streams flowed to the ocean, although at present the depression has no outlet and appears to be surrounded on every side by high land.

The floor of the depression of Kharga is a large, irregular plain from 100 to 400 feet above the sea. It is broken here and there by isolated mesas, flat-topped remnants of the limestone which forms the cliffs. It is also diversified by occasional long bands of sand a mile or two wide, having a trend from north-northwest to south-southeast, at right angles to the prevailing trade-winds which pile the sand into dunes. Somewhat to the east of the center of the depression lies a string of oases and villages extending about 75 miles north and south and divided into a northern group, with Kharga as its center, and a southern group centering around Beris. The villages are poverty-stricken places with flat-roofed houses of adobe, built low and close together. The narrow, crooked streets often run beneath thick arched roofs of mud, built apparently to furnish protection from the intense heat of the summer sun. Around the villages, palm orchards and gardens are carefully irrigated by means of 200 or 300 artesian wells. The rest of the floor of the depression is diversified by patches of tamarisks or reeds in the swampy areas due to the surplus water of the wells, or by drier tracts sparsely clothed with the prickly acacia tree, and the wild Doum palm notable for peculiar branching trunks.

Although the depression of Kharga probably has an area of 25,000 or 30,000 square miles, the population, which is of Arabic origin, amounts to only about 8,500. The number of inhabitants depends entirely upon the supply of water available for irrigation. All the water is derived from artesian wells, for which Kharga has been noted from time immemorial. Some wells which still flow strongly are supposed to have existed for 2,000 or 3,000 years; others of ancient date have dried up; while many flow but feebly. During the last fifty years several score of new wells have been dug, and considerable areas have been added to the districts where cultivation is possible, but the major part of the water supply still comes from wells

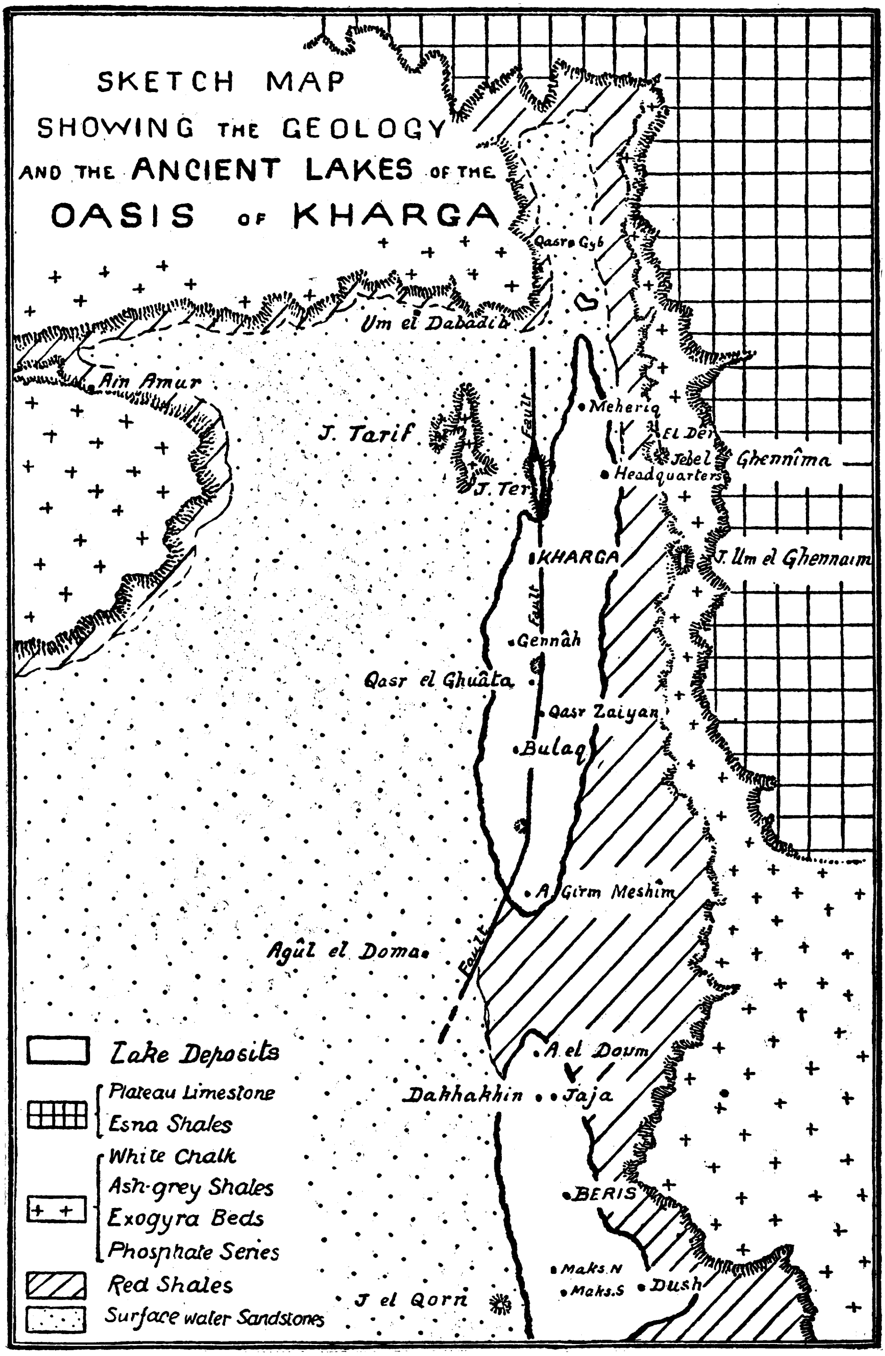

FIG. I.

From "An Egyptian Oasis."

dug as long ago as the Roman or Byzantine period, in the early centuries of the Christian era. In the whole oasis of Kharga there does not appear to be a single natural source of water—nothing but artesian wells. It is not known exactly where the water comes from. Its immediate source is the so-called artesian sandstone which lies at an average depth of about 125 feet. Far away in the swampy regions of the upper Nile this sandstone comes to the surface, and it is supposed that the water of the Nile River sinks into the sandstone and percolates slowly through it, reaching the surface only when artificial wells are pierced in the overlying layer of impervious limestone. In addition to the main artesian sandstone, there is an upper stratum of the same type in which also artesian wells can be sunk. This comes to the surface in certain places and in it water can be obtained by digging to slight depths. Oftentimes, however, the water is saline and not good for irrigation.

The preceding description of Kharga is drawn from a book recently published by Mr. Beadnell of the Egyptian Geological Survey, and entitled "An Egyptian Oasis." The book is noteworthy as a consistent and scientific description of a region of unusual interest. It is truly geographical in distinction from the many so-called geographical books which are mere accounts of travel and of personal adventures. Mr. Beadnell knows Kharga better than does any other living man, and his volume is crowded with facts which are absolutely reliable. So clearly and carefully are they stated that the reader is able to draw his own conclusions, some of which may differ from, or be additional to, those of the author.

The purpose of the present article is to take the facts furnished by Mr. Beadnell and to see what they indicate as to the climatic conditions of the Libyan desert in the historic past. He makes no reference whatever to the subject except to say that in pre-historic times the climate must have been much moister than at present. Apparently, he has not considered the matter, or else accepts as final the statement of certain members of the Meteorological Department of Egypt to the effect that the Nile Valley has suffered no change in climate during historic times. This is not the place to discuss the water supply of Egypt, which depends upon the climate of the equatorial regions far to the south. It must be borne in mind, however, that the climate of equatorial regions may be subject to variations very different from those of sub-tropical countries like Egypt, or it may remain uniform while that of climatic belts farther to the north undergoes marked variations. Kharga and the rest of the deserts of northern Africa must be examined upon their own merits.

The importance of the question of changes of climate is evident from the number of articles which have appeared on the subject during the past five years. Its present status may be judged from the recently published work of various authors. For instance, among Europeans, Woiekof, a Russian who has made extensive studies of the fluctuations of the Sea of Aral and of other Asiatic lakes, is strongly of the opinion that there is no evidence of any important change during the last 3,000 years. All the facts appear to him to point merely to changes which have a period of, at most, a few decades and which have never departed far from the mean conditions of the past century. On the other hand, Hann, the greatest living authority upon climate, comes to quite a different conclusion. In the second edition of his great work upon climate, published in 1897, he discussed periodic variations of climate, such as the 35-year cycles of Bruckner, but came to no conclusion as to climatic variations of longer periods. In his last edition, published in 1908, he says that in view of recent studies in central Asia, "we can scarcely doubt any longer that we have in these districts a general dessication which is still in progress." He goes on to say, "How far in all these accounts we have to do with a progressive dessication and how far with climatic oscillation, is still uncertain." Holdich, one of the foremost English authorities upon central Asia, says that no one will dispute the evidence of dessication, but he can "see at present no evidence" of great oscillations. In America, Ward, Abbe, and other meteorologists agree with Woiekof that the only changes in climate during historic times are those of short period and small amplitude. Bowman, and Moreno, on the other hand, have shown that in South America there is strong evidence indicating that during long periods since the occupation of that country by man the climate has been distinctly moister than during the past century.

Few places offer better opportunities than Kharga for testing the various theories as to climatic changes. The first stage in the recent climatic history of the oasis appears to be recorded in the so-called lake deposits described by Beadnell. They occupy the greater part of an area some 85 miles long and five to ten miles wide at the foot of the cliffs which bound the oasis on the east. Beadnell describes them as consisting "of horizontal, finely-bedded alternations of sand and clay, or more frequently of an intimate mixture of the two; local false-bedding is not uncommon, and included fragments of limestone and sandstone are occasionally met with. The beds have a prevailing brown tint and frequently exhibit well-marked hexagonally disposed shrinkage cracks. Although originally they must have formed an immense, compact and continuous sheet, the deposits have since been subjected to considerable denudation, so that at the present day they exist as large isolated patches" (p. 111). Among the deposits some fragments of pottery were found firmly embedded in clay and also fresh-water shells of *Melania* and *Limnaea*.

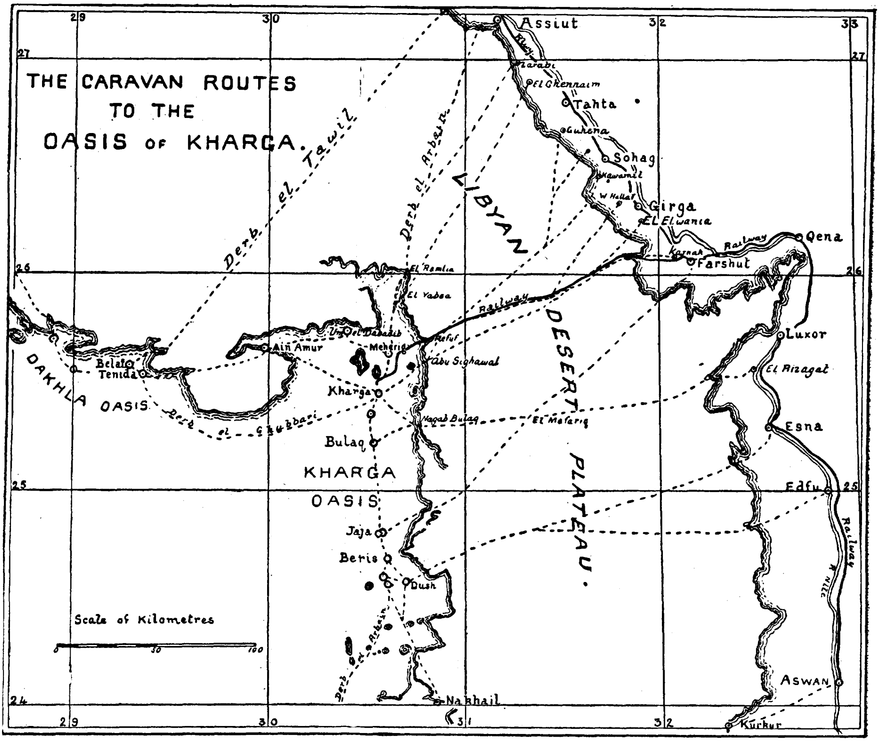

FIG. 2.
From "An Egyptian Oasis."

The upper portion of the clays lies at an altitude which varies from 66 to 83 meters above sea level. Beadnell concludes that "while the lake presumably at one time reached to a maximum level of 85 meters, it stood for a considerable period at about 70 meters above sea level" (p. 116). He believes "that the depression was inhabited previous to the formation of the lake" (p. 116). "The evidence [of this] is . . . . the discovery of a portion of an earthenware pipe imbedded *in situ* in the lake clays at a height of 42.85 meters, of the type used by the ancients for lining their water channels" (p. 120).

In explanation of the supposed lake or lakes in which these deposits were laid down, Beadnell suggests two hypotheses. The first is that when artesian wells were first bored, the water-bearing sandstones were so highly charged with water that the wells overflowed in great volume and formed lakes. The second hypothesis is a modification of the first. It supposes that the lakes were formed when the process of natural erosion first exposed the upper artesian sandstone and thereby allowed water to escape. Neither hypothesis is satisfactory. As Beadnell points out, the flow from a new well is at first rapid, but soon shows a marked decline, and finally settles down to a fairly steady flow, or to a flow which decreases at a constantly diminishing rate. If the discharge from the wells first drilled had been so great as completely to flood the immediately surrounding area, it is scarcely to be supposed that other wells would at once have been constructed. A single well or a dozen wells could not possibly have supplied water sufficient to balance the evaporation of a lake 85 miles long and from five to ten miles wide unless the head of water were scores or hundreds of times as great as it is to-day. The proof of this is found in the fact that the water of the 300 wells, more or less, now in operation, is evaporated from an area not a tithe as great as that of the supposed old lake. Let us assume that as many as twenty wells were dug at the very beginning, and that the evaporation from the surface was four feet per year, which is less than from the Salton Sea under climatic conditions similar to those of Libya. In order to maintain the lake at a constant level, each well would have had to discharge 240 times as much water as the average well of to-day. This would require a tremendous head of water. There is no reason to believe that the head in early days was much greater than at present; for at the depth where the artesian sandstone lies, all rocks in practically all parts of the world are saturated with water. They were saturated in early days and they are saturated to-day, except in the areas immediately surrounding the wells. Under conditions of complete saturation the head of water both in the past and in the present depends in part upon the height at which the water enters the rock and in part upon the amount of pressure exerted by the over-lying strata. These factors must have been essentially the same in the past as in the present.

As to the formation of the lakes according to the second hypothesis, it is sufficient to note one insuperable objection. When natural erosion first exposed the upper artesian sandstones, the topography must have been quite different from that of to-day, for at present the sandstones are exposed for many miles. The lake deposits, however, so far as can be judged, were laid down upon a topography very similar to that now prevailing.

It seems probable that only part of the deposits under discussion were formed in lakes. The nature of terrigenous as opposed to marine deposits, and of subaerial as opposed to lacustrine deposits has only recently been made clear by such men as Davis and others. Barrell has discussed the matter fully,* and has shown that the presence of shrinkage cracks, such as those described above, is a sure indication of subærial rather than lacustrine deposition. The other characteristics of the deposits, such as finely bedded alternations of sand and clay and local false-bedding are also more likely to occur in subærial than in lacustrine strata. Moreover the finding of fresh water shells, such as *Limnaea,* is not consonant with the existence of a lake. If a lake existed here, it is safe to say that it must have been salt, because, in the first place, it would have had no outlet unless it rose higher than the limit of 85 meters indicated by the upper deposits; and, in the second place, it must have existed a long time,—long enough to lay down sediments which appear to have a thickness of a hundred feet. If it had been salt, fresh water shellfish could not have inhabited it. Finally, the finding in the lake deposits not only of pottery at various levels, sometimes 40 meters below the upper deposits, but also of Neolithic flints which appear to have come from the middle clays, indicates that at various periods man lived upon the very areas where deposition took place. Altogether, the facts seem to indicate that a considerable portion of the deposits was laid down on the alluvial fans of streams flowing in from the surrounding plateau, or else in playas and swamps. If a lake actually existed, as seems highly probable, it was quite small at the time when the subærial deposits were laid down. At other times, however, during periods of relatively heavy rainfall, it may have expanded greatly. Such an expansion may account for the fact that Paleolithic implements are found only on the edges of the depression. Before Neolithic man appeared the lake may have contracted so that a part of the floor of the depression became habitable. Still later the water may have risen again, which may

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***Journ. of Geol.*, Vol. 14, pp. 524 ff., 568 ff.

account for the fact that the Neolithic flints are deeply buried. Finally the lake may have retreated once more during the Græco-Roman period in accordance with the conclusion of Beadnell quoted on a later page. In the absence of a series of exact sections showing the succession of beds in the mingled lacustrine and subærial deposits, it is impossible to come to any exact conclusion in the matter. The suggestions here made, however, show that further study of Kharga may give us a full record of climatic pulsations from Paleolithic times to the present.

Whatever may have been the size of the lake, whether large or small, and whatever may be the proportion of alluvial deposits, the facts point clearly to climatic conditions different from those now existing. At present alluvial deposition is not taking place, but on the contrary, erosion is in progress. The nearest approach to lakes is now a few small swamps. If the rainfall of past times were such as to cause streams of sufficient size to flow down from the plateau during the winter, the conditions of both alluvial and lacustrine deposition would prevail. Evidently, some such conditions prevailed during the time when the flints and pottery were deposited. We cannot date the flints, but, as Beadnell says: (p. 118) "The types [of pottery] do not differ in any important respect from those associated with the towns and cemeteries of Græco-Roman age in many parts of the oasis. . . . The pottery, therefore, bears out our conclusions that the lake continued to exist well into the historic period." While there is room for question as to the nature of the deposits in which the pottery is found, we can scarcely question that the climatic conditions which made their deposition possible did continue into the historic period.

In connection with the existence of an ancient lake or of streams which formed large deposits, some notice should be taken of the springs of Kharga. At the present time, as Beadnell tells us, there is no natural efflux of water anywhere in the depression. On the border, however, there are one or two small springs such as Ain Amur, which once supported small settlements, but are now mere water holes. In ancient times the case was different. "The existence of thick deposits of calcareous tufa on the upper portions of the cliffs of the depression suggests a considerable outpouring of water from springs" (p. 112). It is safe to assume that there must have been springs on the floor of the oasis also. We can scarcely suppose that the first drillers of wells were so far advanced in science and art that they sunk wells at points where there was no flow of water. Moreover, if there were springs high up near the top of the cliffs there must have been others lower down. The reason why there is to-day no natural efflux of water in the oasis proper is probably that all the natural sources were early converted into artesian wells. It is interesting to note that all the ancient wells are called *Ain,* which means in Arabic *spring,* while those of modern construction are called *Bir,* which is the common word for *well.* The explanation of this nomenclature may be that the original wells were built where springs were located, but it is equally possible that when the Arabs came to Kharga they found numerous flowing wells and called them springs, not realizing that they were artificial.

The earliest settlers in Kharga certainly did not use artesian wells. Neither palæolithic nor neolithic man was sufficiently skilled to make use of subterranean sources of water. Devoid of all iron tools, as these early people were, they cannot possibly have dug into the solid rock. Their wells must have been mere shallow holes in the soft sand or clay. Nevertheless, primitive man lived in large numbers in Kharga, as is proved by an abundance of flint implements. The palæolithic implements are found chiefly on the edges of the oasis and upon the surrounding plateau, which, as has already been said, suggests that in the earliest days of man the center of the oasis was a lake or swamp, and hence uninhabitable. It suggests also that regions outside the oasis,—districts which are now absolute desert—were then habitable. It is probable that palæolithic man drank from springs which now have disappeared, but whose deposits of tufa still lie upon the upper cliffs.

Turning now to the vicissitudes of Kharga during strictly historic times, we find that in the past the population was much more dense than it is now. A few quotations from Beadnell will show his opinion upon the matter.

"One frequently hears it stated that the oases were far more thickly populated and better watered in olden times than at the present day. This belief is based on the existence in many parts of the depression of extensive remains of temples, forts, and villages, on the widespread traces of formerly cultivated lands, and on the abundance of sanded-up wells. It must not, however, be forgotten that the remains in question belong to successive generations, and that there is as yet no evidence to enable us to determine how much of the land, or how many of the wells, were in use at one and the same time. The evidence is, however, sufficiently pronounced to justify the conclusion that under the Romans the oasis of Kharga was far more flourishing than in modern times, a large part of the population being engaged, not in agriculture but in mining, boring, and in the excavation of subterranean aqueducts" (pp. 156-157) ... "The inhabitants [at the present day, as apparently in the past also] rely almost entirely for subsistence on the products they are able to raise by their own toil and industry. Owing to there being no rainfall, the acreage of land which can be put under crops depends absolutely on the amount of water available for irrigation by wells. The total yield of the latter has, we know, fluctuated to a considerable extent at different times, and one may surmise that, could figures be obtained giving the number of inhabitants and the volume of the water-supply for different periods during the last 5,000 years, a remarkably constant ratio would be observable between the two" (pp. 62-63).

Abundant ruins in places not now occupied and numerous old canals leading from wells now dry support the statements quoted above. It may be true, as Beadnell says, that in Roman days a large part of the population were engaged in "mining, boring, and the excavation of subterranean aqueducts," but, in order to support these artisans and give them work, there must certainly have been a much larger number of people who were engaged in agriculture. If this were so, the agricultural population, and hence the supply of water must evidently have been much greater than at present. In the old days the number of wells was probably not much in excess of that of to-day, for although many have dried up, a large number of others have been bored during the last 50 or 60 years. The ancient wells were not so deep as the modern ones, which is, perhaps, one reason why the modern wells discharge water although many old shafts have run dry or give only a little. Beadnell mentions many instances of ruins where no villages now exist and of land which has gone out of cultivation. For instance, in referring to Maks Kibli, in the southern part of the oasis, he says: "Here as elsewhere in this part of the country much land has gone out of cultivation, though it must be mentioned that the villagers are rather progressive in planting trees and maintaining small vegetable gardens." Farther south he mentions a well, Ain Mabruka, which "just trickles and irrigates a tiny area of not more than a few square meters. This is the most southerly point at which exposed water is to be seen, though in the midst of a large area of scrub still farther south a sanded-up well by the name of Ain El Terfai is reported to exist" (p. 85). Another place where the flow of water must have seriously diminished, is Dakhakhin. "The ancient Dakhakhin must have been as ugly as the modern village is pleasant . . . . the ruins are only slightly above the level of the plain, but cover an area many times greater than that occupied by the modern village. This circumstance alone shows how insignificant is the present flow compared with what it must once have been" (p. 80). Again, "At Ain Bella . . . . there are at present only a few acres under cultivation, but the tract anciently tilled is seen in the eroded remains of an alluvial platform to the northeast. This is now a deeply grooved and ridged hummocky area of loam full of dead palm stubs with rootlets ramifying in every direction. The original terrace [that is, cultivated alluvial platform] appears to have extended far to the north. . . . At one time or another many wells existed to the west but are now buried in the dunes, their former presence being testified by isolated exposures of arable land, and by occasional trees and bushes. The dunes following their natural S.S.E. course in the direction of the prevailing winds, seem to be still encroaching on the belt of country occupied by the existing wells and cultivated lands, and it is probably only a matter of time, perhaps a few hundred years, before they blot out the whole of the south part of the oasis. The sand speedily envelops any settlements which are abandoned, as nothing encourages the formation of dunes to such an extent as vegetation, and this nearly always abounds in the neighborhood of the wells" (pp. 83-4).

Facts such as these and many others show unquestionably that the area under cultivation has greatly diminished during historic times. They show further that at present the encroachment of sand is a very serious matter. The statement that nothing encourages the formation of dunes to such an extent as vegetation is only partially true. In Chinese Turkestan the writer observed again and again that dunes of great size grow up upon the edge of an area of vegetation, but do not penetrate very far into it. In the same regions it was also noticeable that wherever vegetation had died, there the sand began to move. If the climatic conditions of a country remain stable for any length of time, the dunes of interior regions away from the seashore advance only until a certain point of equilibrium is reached. Thereafter the sand encroaches not at all or only at an imperceptible and constantly diminishing rate. The fact that dunes are now advancing upon cultivated regions shows that in relatively recent times there must have been some change in the conditions of vegetation.

Another point which indicates that present conditions are different from those of the past is the roads leading out from the oasis. One such road once ran from Kharga westward 500 miles to Kufra, passing to the south of a great area of sand dunes. "It is probable." says Beadnell, "that within the last century the area of this sand has extended considerably to the south, as an old caravan road trending westwards and believed originally to have connected the oases of Dakhakhin and Kufra is now lost in the dunes" (p. 4). In the same way, from the spring and ruins of Ain Amur, "very old tracks trending in a westerly and northwesterly direction are noticeable, and although unused at the present day these may mark the presence of former frequented routes leading to the oasis of Farafra. At the present time that oasis is not in direct communication with Kharga, the routes used being from Manfalut in the Nile Valley, from Qasr Dakl in the oasis of Wakhla and from Ain el Hais in Baharia" (p. 38). These two abandoned roads have not been carefully investigated, but what is known of them suggests that at the present time the Libyan desert is much more difficult to traverse than in the past. A similar suggestion is given by the water stations along the old Roman roads which connected Kharga with the Nile valley. One such is found in El Tundaba, a deep shaft sunk in a hollow full of silt in the plateau half way from the Nile to the oasis (p. 29). The shaft and the hollow are now quite dry, but flints, pottery and graves indicate that the place was once the site of a settlement. It cannot be inhabited to-day, and the chances are that it could not have been inhabited in the past, if present conditions had then prevailed.

The last line of evidence as to the ancient water supply is found in a number of tunnels at Quasr Lebekha, Quasr Gyb, and especially Um el Dabadib, in the northern part of the Kharga depression. They are dug in the upper artesian sandstone. At the latter place there are in all four main tunnels varying in length from two to four miles. One of the tunnels has recently been thoroughly cleared out and is now in use, so that it is possible to estimate the relation between the amount of labor involved and the results obtained. The tunnel is "distinctly coffin shaped in cross section, being widest near the roof and tapering downwards" (p. 174). It measures roughly five by two feet. The tunnel is reached by vertical shafts about five by two and one-half feet in size and varying in depth from a few feet near the mouth of the tunnel to 175 feet at the inner end. The shafts number 180 and are placed at intervals of about 65 feet on an average. The length of the main tunnel is 1.8 miles. The amount of vertical excavation for the shafts amounts to over two miles. Various branches and curves add somewhat to the length, so that the total excavation was fully four miles. Beadnell is impressed by the amount of labor in proportion to the results obtained. He says, "Although it is difficult to believe that the supplies of water obtained were commensurate with the time and labor involved in the construction of the collecting tunnels, we may safely assume that the engineers who so carefully planned and carried out the works had fully considered the results to be looked for. The ruins of villages and the traces of formerly cultivated tracts show that sufficient water was obtained to enable fairly large colonies to exist, though after the withdrawal of the Romans these outlying districts were abandoned, the aqueducts silted up, and the cultivated lands reverted to the desert" (pp. 170-171).

The tunnel, as we have said, was cleaned out a few years ago, and "water again flowed from the mouth of the aqueduct and enabled a small agricultural colony to establish itself on the site of the original founders" (p. 171). The tunnel is now in excellent repair, as Beadnell found upon traversing it to the upper end. In January, 1905, the discharge "from the mouth of the aqueduct was between thirty and thirty-five gallons per minute; a dozen acres or so of land had been reclaimed and were tended by seven or eight men, who informed me that the crops reaped there were equal to those in any part of the oasis" (p. 172).

A careful examination of the facts stated above shows that whereas in Roman times these tunnels enabled "fairly large colonies to exist," the tunnel which has now been re-excavated serves only to irrigate "a dozen acres or so of land." In other words, if the conditions of the past were like those of the present, "the engineers who so carefully planned and carried out the works" thought it worth while to excavate a tunnel about 1,800 feet long for every acre of land to be irrigated. The average well in Kharga, including old and new, good and bad, yields about 35 gallons of water per minute, which, as we have seen, is equal to the present discharge of water from the tunnel. The depth of a well varies from 125 to 800 feet. Wells of the latter depth were certainly rare in ancient times, and there is no reliable evidence that any were so deep. The average well does not seem to have been over 250 feet deep. Assuming still that past conditions were like those of the present, we must conclude that the Roman engineers, in order to secure an amount of water equivalent to that from an average well, went to the labor of excavating tunnels and shafts four miles in length and with a size of five by two feet. In constructing an ordinary well the first process is to dig a hole about 100 feet deep and six feet square which would require the excavation of nearly 150 cubic yards of rock. Then a shaft perhaps 8 inches in diameter is drilled for the remaining 150 feet. The latter process is difficult, but, nevertheless, wells were drilled by the hundred in ancient times. Compare with this the labor of building a tunnel and shafts to a length of four miles. The total amount of excavation involved in building the single tunnel which has been opened is estimated by Beadnell at 4,875 cubic meters or 5,850 cubic yards. Such work was more difficult than the excavation of a large open well like that which under native methods was constructed as the first stage in boring a well; for the space where work was carried on was cramped, only one person could work at a time, and all the excavated material had to be carried to the shafts and hauled up, sometimes as far as 175 feet. To put the matter concisely the digging of a well involved the excavation of about 150 cubic yards of material, and the boring of a hole less than a foot in diameter and 150 feet deep. The excavation of a tunnel, on the other hand, involved the excavation of 5,850 cubic yards. In other words, if we deduct the excavation of 150 cubic yards of material from the labor involved in each case, we find that in order to get a yield of about 35 gallons per minute the driller of the well had to bore a hole only 150 feet deep, whereas the makers of the tunnel had to excavate 5,700 cubic yards of sold rock, digging a tunnel and shafts to the length of four miles.

The following quotation from Beadnell shows with what skill the Roman engineers carried on their work: "That the tunnel was most carefully planned and excavated is evident from its very low and gradual slope, as is indicated by the depth of water flowing through and by the generally unrippled character of the stream. Judging by the height of the mouth of one of the man-holes near the point of origin of the tunnel, and by its depth to the stream in the tunnel below, there only appears to be a fall of one meter in about 2½ kilometers, or a slope of 1 in 2,670" (p. 178).

There can be no question that the ancient engineers were skilled in their art. It is evident that such men would never have dug tunnels if, by scarcely one-hundredth as much labor, they could have drilled wells capable of supplying an equal amount of water. It may be thought that perhaps when the tunnel was first dug the yield of water was exceptionally large because new areas of rock were being continually opened. There may be some truth in this, but inasmuch as only one man could work in the tunnel at a time, and inasmuch as shafts had to be dug from above before excavation could go on, the progress of the tunnel must have been so slow that the effect of the opening of new rock must have been slight. By the time the work had paused long enough to allow a shaft to be sunk from above, the tunnel could scarcely have produced a flow much in excess of that which continued permanently. The upper artesian sandstone in which the tunnels were dug is exposed at the base of the cliffs bordering the oasis. Hence both before and after the construction of the tunnels it was subject to natural drainage through springs. Therefore, it contained no stored up supply of water like that found in the other sandstone, far below the surface. The only reasonable supposition seems to be that when the Romans built these great irrigation works, the sandstone contained a much larger supply of water than at present. Such a supply of water can have come only from increased rainfall.

We have now seen that there is close agreement among many lines of evidence such as lacustrine or alluvial deposits, ancient spring deposits, ruins, ancient areas of cultivation, diminishing wells, roads in the desert, and tunnels where now no tunnels would be built. All these varied phenomena are explicable if we suppose that the average climate for many centuries in the past was distinctly moister than the average climate of to-day. Let us now see whether there is any evidence to show how the change from the past to the present took place. Was it a steady decrease in rainfall or did occasional periods of exceptional aridity alternate with moister epochs?

In prehistoric times human occupation of the country around Kharga seems to have been more extensive than at any succeeding period. During the palæolithic stage of development men occupied not only the floor of the Kharga depression but also the surrounding plateau; in the neolithic stage the area of occupation had decreased and the population was apparently most dense on the border of the depression near the foot of the cliffs. The center perhaps was occupied by lakes or swamps. Coming down to historic times we have records which tell us that Egyptian kings claimed allegiance of the inhabitants of the oasis as far back as the 18th dynasty, 1545-1250 B. C. In Kharga itself the oldest ruins are those which belong to the time of Darius, about 500 B. C. At that time the Persians cultivated the oasis and built various temples, among which the temple of Hibis is still standing. This must have been a period of great prosperity, but our information in regard to it is very slight. Other ruins date from the time of the Ptolemies, and still more from the Roman period, beginning about fifty years before Christ, and lasting until A. D. 395. During the latter part of the Roman period the oasis was perhaps less prosperous than before or afterward; for there was much less activity in architecture than there had been in early Roman days or than there was during the Byzantine era which immediately succeeded it.

In regard to the location of ruins Beadnell makes an interesting statement. "In the first place," he says, "they are mostly on or near the extreme margin of the lacustrine deposits; secondly, they are absent altogether from the central portion of the lake site; and thirdly, the older monuments occupy the highest levels, while there are no representatives at all of the earlier Egyptian periods. While the disposition of the monuments may, of course, be entirely fortuitous, we are justified, I think, in assuming that the lake existed well into the historic period, and may have still stood at the 65 or 70 meter level when the temple of Hibis was erected by Darius, about 500 years before the commencement of the Christian era. In the time of the Ptolemies, it was certainly considerably lower, while in still later days, when the country became a Roman province, the lake had very much contracted, and probably only existed as a marshy swamp occupying the lower portions of the depression" (pp. 117-118). It is worth noting that during this period when according to Beadnell the lake was steadily decreasing in size, there was a great development of irrigation works. To quote from our authority once more:

"It was during the sway of the Roman Emperors that the Egyptian oases attained their maximum importance. During this period from 30 B. C. to about the beginning of the seventh century, extensive towns existed in Kharga, and the oasis was strongly garrisoned and protected by forts. Temples and other edifices were erected, while a great development of the water-supply took place. During the same period the oases were used as places of banishment, just as they were in earlier days under the Pharaohs, and have been, in a way, in quite modern times. Juvenal, the Latin satirist, was banished to Syene at the beginning of the second century, as a punishment for his attacks on the Court, and he appears also to have been for a time confined in Kharga; Athanasius, Nestorius, and other celebrities likewise made unwilling acquaintance with this portion of the Empire. Sayce remarks that the oases under the Romans were thoroughly cultivated, a brisk trade in wine being carried on, and mentions that on one of the temple walls there are several inscriptions which lead one to infer that Kharga yielded a considerable revenue . . . . . . (p. 94).

"Although the Persians and Romans left abundant traces of their occupation of the country in the shape of temples, forts, and monasteries, the determination and energy with which they prosecuted the colonization and general development of the oases is best shown by their attention to works of public utility. At no period in the history of the oases has so much attention been paid to the water-supply. Not content with tapping the deep-seated sources by means of bores, they carried out underground works of considerable magnitude and involving engineering difficulties of no mean order, so as to obtain additional supplies from the sandstones lying at or near the surface. The methods employed were probably introduced from Persia, where underground aqueducts, or 'kareez' for the transference of water from one locality to another, have from an early date been employed. At the same time, judging by the character of the ancient buildings in the immediate neighbourhood of the most important of these works, it seems probable that the latter were for the most part constructed by the Romans" (pp. 167-8).

These long quotations have been inserted because of the significant fact that irrigation works were developed at just the time when the lakes were drying up, or when the streams which supplied the alluvial deposits were diminishing. Apparently, this great activity in digging wells was due to the fact that during the period immediately after the time of Christ especial need was felt for a larger supply of water.

Before leaving the ancient history of Kharga, another fact deserves to be recorded. In those days Kharga and the oasis of Dakhla, 75 miles further west, were included under the common name "The Great Oasis." To-day they are distinctly two oases separated by many miles of desert. They would scarcely have been called one oasis unless they had had a closer connection than that of to-day. Such a closer connection would only have been possible if the intervening country were moist enough to be inhabited.

The further history of Kharga may best be described by quoting once more: "With the withdrawal of the Roman garrisons and the Mohammedan conquest decay set in, and, as Sayce remarks, the aqueducts became choked, the fields were neglected, and malarial fever invaded a district which had at one time been regarded as a health resort.

"Of the history of the oases during the succeeding seven or eight centuries no records are available, but, judging from the writings of Arabian geographers, between the eleventh and the fifteenth centuries, it is evident that they gradually became depopulated, and were regarded as of little importance. El Sherif el Edrissi, writing about the middle of the sixth century of the Hegira (1150 A. D.), refers to the oases (Al Vahat) as places formerly containing streams of water, with lands on which trees were still found growing, and with ruined, uninhabited towns. He adds that the goats and sheep had become quite wild, and were trapped by hunters like other wild animals" (p. 108). Beadnell is inclined to believe that Edrissi's statement cannot refer to Kharga proper, but to some outlying region. "It seems" he says "extremely unlikely . . . that the Great Oasis as a whole had become entirely uninhabited." To the writer of the present article this does not seem at all unlikely. As he has shown elsewhere, the twelfth century appears to have been a period of extraordinary aridity, second only to that of the seventh century, and aridity would inevitably cause depopulation in Kharga.

Yakut, an Arabian historian, writing about 1225 A. D., speaks of three oases in this region and refers to the first of them as being well cultivated, containing streams and hot springs, palms and cultivated lands. His description suggests that Kharga was more prosperous in his day than it had been three quarters of a century before in the times of Edrissi. Ismail Abulfida, writing about 1300 A. D., speaks in still better terms of the oasis, which in his day abounded with palms and running water. Since that time we have practically no information until about a century ago.

The various phases through which the history of Kharga has passed may now be summed up and compared with the climatic vicissitudes of the country. Up to the time of Christ and on until the third century of our era the fortunes of Kharga were relatively high. Toward the end of the Roman period they declined somewhat, but rose again during the Byzantine period, from the fourth to the sixth century. Then in the seventh century they fell to a most deplorable condition. During the years that followed we have no information as to the fate of the oasis till the days of Edrissi in the twelfth century. Then, again, if the Arab writer is to be believed, Kharga was in a state worse by far than to-day. Soon, however, she rose once more, and at the beginning of the fourteenth century enjoyed a certain degree of prosperity. Since that time there may have been a little falling off, although here again our information is scanty. In regard to the water-supply, all the evidence points to a decrease since the time of the Persians. Apparently, this had no great effect until the time of Christ or afterward. Even at that time, if our conclusions are correct, it was not particularly harmful, because the decrease in the natural supply induced the people to provide an artificial supply, and thus, perhaps, stimulated rather than hindered industry and civilization. Between the period of decay toward the end of the third century, when the power of Rome was waning, and the brilliant Byzantine period some two hundred years later, we have, in Kharga itself, no evidence of any change of climate. Nevertheless, if Beadnell's repeated statement as to the close relation between density of population and prosperity, on the one hand, and water-supply, on the other, is true, the Byzantine period was probably somewhat moister than the latter part of the Roman period. Judging from the extreme depopulation in the seventh century the early Mohammedan days must have been a time of great aridity, although the general commotion which then took place in western Asia and northern Africa makes it impossible to draw any positive conclusions from Kharga alone. During the succeeding five centuries we have no definite information as to Kharga, but in the twelfth century we find it again almost depopulated, a condition which suggests but does not prove great aridity. In the next two centuries there seems to have been an improvement in the habitability of the oasis. How that time compared with the present it is impossible to tell.

A comparison of the history of Kharga with the climatic pulsations of which evidence is found in Central and Western Asia is highly instructive. The pulsations are represented in the accompanying curve (Fig. 3), which is taken from the author's volume "The Pulse of Asia," but has been modified somewhat to make it conform to new data obtained during the Yale Expedition of 1909 to Palestine. Horizontal distance represents time, and vertical distance the amount of rainfall. Thus the curve is high during moist periods and low when the climate is dry. The curve is based upon a large body of facts as to the abandonment of ruins, the giving up of old roads because of lack of water, the fluctuations of enclosed lakes, and the disappearance of springs and other sources of water. It will be seen that it agrees exactly with our inferences in regard to Kharga. So far as our information goes, the Libyan oasis has prospered and had a large supply of water at exactly the times when the climate of western and central Asia has been comparatively rainy. Its supply of water has decreased and its population has diminished

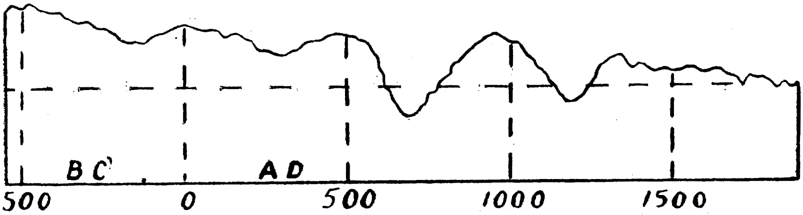

FIG. 3.

coincidently with similar events in Asia. So close an agreement among the phenomena of regions extending from Lybia through Arabia, Persia and Turkestan to the far confines of China, would scarcely be found unless the whole area had been subjected to a uniform series of important climatic pulsations.

THE ISLAND OF SÃO THOMÉ.

It is believed that no tropical country to-day possesses, for so small an area, a degree of economic prosperity that is comparable with that of the Portuguese province of São Thomé and Principe. They have advanced, in a few years, to the first place among the cacao producing countries, wresting the primacy from Ecuador, which had long held the first place. In 1905, their production was 23,187 tons, while that of Ecuador was 18,268 tons. The new development of agriculture in São Thomé dates only from 1870, but in 1904 it was exporting annually over $6,000,000 of cacao and coffee. Perhaps, in our day, there has been no agricultural development comparable with this, in so short a time and with so little capital and so small a force of toilers.

For some years past Mr. Aug. Chevalier has been in the service of the French Government studying the agricultural possibilities in the chief African colonies and looking for favorable places at high